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Fiery Ice from the Seas— The First Workshop of the International Committee on Methane Hydrates

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14. ABSTRACT

This document reviews an expert workshop on methane hydrates, held in Honolulu, Hawaii, at the International Imin Conference Center of the East West Center on March 7-9, 2001. The workshop was organized by the Hawaii Natural Energy Institute of the University of Hawaii and the Environmental Quality Sciences Section of U.S. Naval Research Laboratory, in cooperation with the Hokkaido National Industrial Research Institute of Japan's Agency of Industrial Science and Technology, and Inha University of Korea. Fifty-eight participants from the United States, Japan, Korea, Canada, Norway, Russia, and the United Kingdom attended the workshop. Participation was by invitation only. Attendees included some the world's leading researchers in methane hydrates, and representatives from government agencies and the private sector. The principal workshop objectives were: (1) review past, ongoing, and planned methane hydrates R&D projects and programs; (2) share information on budgets and research resources and priorities in different countries; and (3) establish linkages for domestic and international partnering. The program of the 2-1/2 day workshop included plenary lectures, panel discussions, small group breakout meetings, and a poster session. It was conducted as a working event where all participants conferred to develop a roadmap for future collaborative studies of methane hydrates.

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International Committee on Methane Hydrates

7-9 March 2001
International Imin Conference Center
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Honolulu, Hawaii

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ABSTRACT

An expert workshop on methane hydrates was held in Honolulu, Hawaii at the International Imin Conference Center of the East West Center on March 7-9, 2001. The workshop was organized by the Hawaii Natural Energy Institute of the University of Hawaii and the Environmental Quality Sciences Section of U.S. Naval Research Laboratory, in cooperation with the Hokkaido National Industrial Research Institute of Japan's Agency of Industrial Science and Technology, and Inha University of Korea. Grants of $10,000 each were awarded by the Office of Naval Research-International Field Office and the National Energy Technology Laboratory of U.S. Department of Energy to support the event. Additional funds were provided through the Hawaii Energy and Environmental Technologies (HEET) initiative sponsored by the U.S. Department of Defense through the efforts of U.S. Senator Daniel K. Inouye of Hawaii. The Department of Business, Economic Development and Tourism (DBEDT) of the State of Hawaii and the Pacific International Center for High Technology Research (PICHTR) also supported the workshop.

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EXECUTIVE SUMMARY

An expert workshop on methane hydrates was held in Honolulu, Hawaii at the International Imin Conference Center of the East West Center on March 7-9, 2001. The workshop was organized by the Hawaii Natural Energy Institute of the University of Hawaii and the Environmental Quality Sciences Section of U.S. Naval Research Laboratory, in cooperation with the Hokkaido National Industrial Research Institute of Japan's Agency of Industrial Science and Technology, and Inha University of Korea. Grants of $10,000 each were awarded by the Office of Naval Research-International Field Office and the National Energy Technology Laboratory of U.S. Department of Energy to support the event. Additional funds were provided through the Hawaii Energy and Environmental Technologies (HEET) initiative sponsored by the U.S. Department of Defense through the efforts of U.S. Senator Daniel K. Inouye of Hawaii. The Department of Business, Economic Development and Tourism (DBEDT) of the State of Hawaii and the Pacific International Center for High Technology Research (PICHTR) also supported the workshop.

The workshop was the first in what is intended become a series of gatherings that will stimulate and support international cooperation in gas hydrate research and development. A second workshop is planned for the summer of 2002.

Fifty-eight participants from the United States, Japan, Korea, Canada, Norway, Russia, and the United Kingdom attended the workshop. Participation was by invitation only. Attendees included some of the world's leading researchers in methane hydrates, and representatives from government agencies and the private sector.

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Research priorities were identified during the breakout sessions and included:

Experiments

- observation, recovery, and analysis of natural hydrate samples;
- expand range of structural and thermochemical property data;
- establish standardized protocols and laboratory calibrations;
- development of tools for *in situ* microscopic measurements;
- development of field instruments to detect, characterize, and sample and transport hydrates;
- develop means to calibrate and validate detection and characterization instruments;

Modeling and Analysis

- development of a hydrates systems model;
- development of a predictive model of methane transport through the water column;

- conduct an engineering systems analysis for a methane gas production from hydrates;
- conduct an analysis of the environmental impacts of hydrate resource development;

Databases and Information Sharing

- perform a review and analysis of existing field data;
- establish a shared database;
- establish agreements for geohazard information sharing;

Other Issues

- perform a thorough review of relevant laws, statutes, and treaties

During the panel discussion and open forum on the final day of the workshop, there was a general consensus that, given the broad scope of the topic, international collaboration is essential to ensure that adequate R&D progress is made with the limited funds currently available. One obvious step in this direction would be expanded information sharing, possibly through the establishment of a comprehensive, accessible database. There was discussion about whether a top-down or bottom-up approach (i.e., collaboration driven by the funding agencies or by the efforts of researchers) would be more productive, with opinions expressed in support of both positions. Many participants articulated their concern over the relative lack of interest by the oil and gas industry in methane hydrates as a future energy resource and conceded that industry participation would have to be engaged through their immediate interest in flow assurance, seafloor stability, and the development of small gas fields.

Comments and recommendations made during the panel discussion and the open forum included:

- The oil and gas industry has an obligation to its shareholders to make a profit. From this point of view, industry probably will not invest significantly in high risk research to develop a new energy source (i.e., methane gas from hydrates) whose production economics are very unclear. Industry may fund studies that support existing systems that produce natural gas. There is interest by the oil and gas companies in areas relevant to ongoing exploration and recovery activities such as preventing or remediating hydrate blockage of subsea conduits in production areas, the collection and transport of stranded gas, seafloor stability, and certain environmental issues.

- There is no reality benchmark at this point in time for the commercial production of gas from hydrates. Hence, a critical step in engaging industrial interest would be to provide proof of concept of a production system and to identify credible costs.

- While large oil companies and other major industrial entities may be hesitant to invest in what is perceived as a high risk initiative, small, entrepreneurial companies are expected to vigorously pursue this opportunity; these companies are likely to do much of the early development.

- It was recommended that studies first be conducted at "sweet spots" that can offer the advantages of high concentrations of hydrates and free gas reservoirs. Production and transportation studies conducted under such favorable conditions have an enhanced

probability of success; the results could then be transferred to lower concentration fields where conditions are more challenging.

- It was suggested that the relevance of methane hydrates to topics other than energy supply be emphasized to engage funding support. For example, there is significant political and public interest in environmental issues such as global climate change and ocean development, both of which can be impacted by marine methane hydrates. From a military perspective, hydrates can result in bottom loss for low frequency sonar and affect navigation.

- Increasing public perception about methane hydrates, if done properly, could increase the amount of funds available for R&D. An outreach program should be considered.

- Significant efforts should be made to initiate the process of putting in place international (government) commitments to pursue jointly funded studies. A critical step would be to select appropriate sites for field tests.

- There are a number of developing countries that may have a need for the energy and a viable methane hydrate resource, but not the capital nor the technology to develop that resource. Cooperation with those countries could yield substantial benefits for all parties and should be seriously considered.

FIERY ICE FROM THE SEAS

The First Workshop of the International Committee on Methane Hydrates

I INTRODUCTION

Methane hydrates represent an enormous untapped hydrocarbon resource with an energy content that exceeds all other known fossil fuel reserves. Estimates of the total volume of hydrocarbon gas locked in hydrate deposits worldwide range widely from about 10^5 trillion standard cubic feet (TCF) to 2.7×10^8 TCF (i.e., 2.8×10^{15} to 7.6×10^{17} cubic meters). Even at the lower end of this range, the methane hydrate resource has the potential to contribute significantly to supplying the energy needs of the world, if practicable recovery techniques can be developed.

Hydrates are crystalline solids comprising water molecules linked by hydrogen bonds in a tight polyhedral cage structure. Guest molecules, which can include various hydrocarbons found in natural gas mixtures, reside in the interstices of this lattice. Methane (or other hydrocarbon) molecules are packed closely together in the hydrate lattice. A cubic meter of hydrate yields about 160 cubic meters of methane at standard temperature and pressure and about 0.87 cubic meter of water. This relatively high energy density has motivated studies to investigate hydrates as an alternative means to transport and to store natural gas.

Methane hydrates are found in high pressure, moderate temperature regimes in ocean sediments and low temperature Artic permafrost zones. Methane hydrate is stable in seafloors below about 450 meters water depth in open oceans with an average temperate hydrothermal profile. Significant hydrate deposits have been identified worldwide in undersea basins on continental margins. Sediment layers in deep ocean basins also may contain large deposits of methane hydrates, but these areas have not been yet been thoroughly explored. Figure 1 shows a surface outcropping of methane hydrates encountered in the Gulf of Mexico.

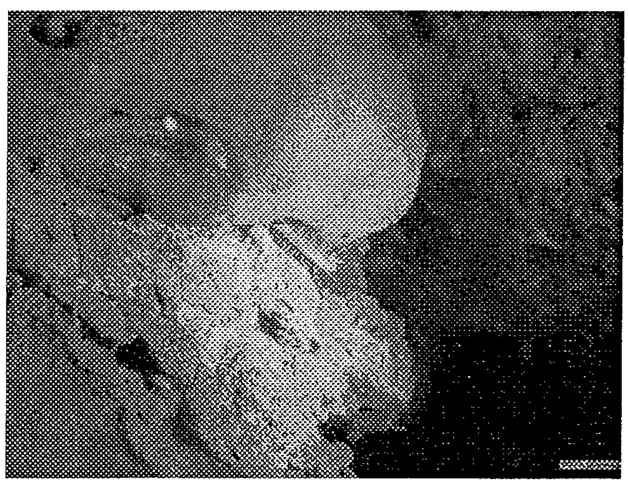

Figure 1 Methane hydrates (yellow color) on the sea floor in the Gulf of Mexico.

During the first half of the twentieth century, blockage of natural gas pipelines by methane hydrates posed a serious problem for the petroleum industry. Research was initiated to study hydrate properties and formation and dissociation phenomena; and to develop means to inhibit and remediate hydrate formation in pipelines. After solutions to the pipeline blockage problem had been identified and implemented, interest in methane hydrates waned. Naturally occurring methane hydrates remained largely a curiosity for many decades, with limited practical use.

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Beginning in the early 1990's, interest in methane hydrates began to revive. While offering tremendous opportunities as a future energy resource, sedimental marine hydrate deposits also emerged as an immediate and formidable nuisance to offshore oil and gas operations, compromising seafloor stability and imperiling drilling activities. The hydrate problem has become more critical as oil and gas exploration and recovery move into increasingly deeper waters where hydrates abound. From a military perspective, it was recognized that characterizing the geo-acoustic properties of hydrate sediments was important to a number of naval operations, such as surveillance and mine detection. Finally, methane hydrates may exercise a profound effect on the global climate if the carbon sequestered in these solids is released into the environment by commercial exploitation of the fuel or through destabilization and outgassing induced by ocean warming.

II GLOBAL METHANE HYDRATE R&D PROGRAMS

In response to the potential and peril posed by methane hydrates, national gas hydrate research programs have been established in Japan (1995), India (1996), and the U.S. (2000). Hydrate R&D also is being actively pursued in a number of other countries, including Russia, Canada, Korea, and several nations of the European Union.

Japan

The Government of Japan established its first large-scale national exploratory hydrate research program in 1995. In 1998, the Japan National Oil Corporation sponsored drilling tests of known hydrate deposits in the McKenzie Delta in Canada. Another multi-year program was recently authorized, which will be overseen by the New Energy and Industrial Technology Development Organization (NEDO), a public corporation whose operating budget is provided largely by the Ministry of Economy, Trade and Industry (METI). The current goal of the Japanese program is to demonstrate the viability of commercial-scale production of natural gas from undersea hydrates within the Japanese EEZ by 2010.

India

In 1996, India became the second nation to establish a hydrate research program. The Oil Industry Development Board of India earmarked $56 million for an effort to be carried out under the auspices of the Gas Authority of India. Industry cooperation is essential to this initiative; however, low energy prices have reduced incentives and hampered progress.

U.S.

In May 2000, U.S. Public Law 106-193 authorized the establishment of a national methane hydrates program. This program is administered by the U.S. Department of Energy in cooperation with the Naval Research Laboratory (NRL) and the United States Geological Survey (USGS). The Secretary of Energy is charged with oversight to ensure that (1) partnerships are established between government, industry, and academia to research, identify, assess, and explore methane hydrate resources; (2) programs are developed to secure basic information needed to promote interest in methane hydrates as an energy source; (3) data and information are accessible

and widely disseminated as needed and appropriate; and (4) that there is cooperation among agencies developing technologies for application to the methane hydrate resource.

Korea

Korea, which like Japan is deficient in indigenous fossil energy resources, has been closely tracking developments in Japan and the United States. The existence of methane hydrate deposits in the Sea of Japan adjacent to the Korean peninsula has prompted a number of national laboratories and universities to actively lobby the Government of Korea to establish its own program. Limited studies are being conducted at these laboratories and universities.

Canada

Canadian methane hydrate development recently has focused on deposits in the McKenzie Delta in the Arctic region and the Cascadia Margin along the southwestern coast of Canada. This effort has involved international cooperation with Japan and the U.S.

Russia

Methane hydrates research activities have been ongoing for many years in Russia. Currently, Russian scientists are conducting coring and submarine dives in the Norwegian-Greenland sea to assess the methane hydrate resource and to investigate formation and stability phenomena.

III INTERNATIONAL PARTNERSHIP

Against the backdrop of growing worldwide interest in marine methane hydrates and expanding RD&D activities, the Hawaii Natural Energy Institute (HNEI) of the University of Hawaii and NRL agreed to collaborate on an effort to promote international research partnerships. The rationale for this focuses on the global implications of developing the methane hydrate resource and the significant advantages that can be realized through international cooperation. It was recognized from the start that the viability of these partnerships would depend on striking a balance between national interests and international benefits and responsibilities.

As an energy resource, substantial deposits of methane hydrates exist in coastal regions, within national Exclusive Economic Zones (EEZs). This suggests that disputes over recovery rights should be limited and resolvable under existing treaties, and that, overall, individual nations stand to benefit directly from timely exploitation of their offshore hydrate reserves. It is, therefore, in the general best interests to pool resources and work cooperatively to obtain a comprehensive understanding of the global methane hydrate resource and to develop practicable recovery processes and safety procedures.

Fuel production from methane hydrates could profoundly restructure the world economy. Furthermore, global climate may be affected as carbon sequestered in these hydrates is released into the environment as a result of this resource utilization or inadvertently through destabilization and outgassing induced by ocean warming. The international community will share the associated burdens and benefits. This common interest supports an international approach to address key research issues.

At the beginning of 1999, HNEI and NRL began contacting potential foreign research partners. Groups from Korea, Japan, and Norway agreed to collaborate on methane hydrate projects and several joint investigations are underway. Partners include the Hokkaido National Industrial Research Institute of the Agency of Industrial Science and Technology of the Government of Japan, Inha University of Korea, the Norwegian Institute for Water Research, and the University of Bergen, also of Norway. Discussions are ongoing with other national agencies and universities in Japan and Korea; and organizations in India, Canada, and Russia. It is anticipated that this expanding international effort will yield significant intellectual and financial benefits and result in accelerating the attainment of specific research goals for the participating nations.

IV INTERNATIONAL WORKSHOP

As part of the effort to promote international RD&D partnering in the area of methane hydrates, HNEI and NRL decided to hold a workshop to establish an informal international research committee and network and to provide a forum to review past and ongoing work. This opportunity would be employed to identify critical research needs and to initiate development of a strategy for international cooperation to address these needs.

The expert workshop on methane hydrates was held in Honolulu, Hawaii at the International Imin Conference Center of the East West Center on March 7-9, 2001. The workshop was organized by HNEI and the Environmental Quality Sciences Section of NRL, in cooperation with the Hokkaido National Industrial Research Institute of Japan's Agency of Industrial Science and Technology, and Inha University of Korea. Grants of $10,000 each were awarded by the Office of Naval Research-International Field Office and the National Energy Technology Laboratory of U.S. Department of Energy to support the event. Additional funds were provided through the Hawaii Energy and Environmental Technologies (HEET) initiative sponsored by the U.S. Department of Defense through the efforts of U.S. Senator Daniel K. Inouye of Hawaii. The Department of Business, Economic Development and Tourism (DBEDT) of the State of Hawaii and the Pacific International Center for High Technology Research (PICHTR) also supported the workshop.

The workshop was the first in what is intended become a series of gatherings that will stimulate and support international cooperation in gas hydrate research and development. A second workshop is planned for the summer of 2002. Venues in Washington, D.C., Japan, and Norway are being evaluated.

Fifty-eight participants from the United States, Japan, Korea, Canada, Norway, Russia, and the United Kingdom attended the workshop. Participation was by invitation only. Attendees included some of the world's leading researchers in methane hydrates, and representatives from government agencies and the private sector. A list of participants is provided in Appendix A of this report.

IV.1 WORKSHOP OBJECTIVES

The principal workshop objectives were to:

(1) review past, ongoing, and planned methane hydrates research and development projects and programs and identify research needs;

(2) share information on budgets and research resources and priorities in different countries; and

(3) establish linkages for domestic and international partnering.

The workshop was conducted as a working event where all participants conferred to develop a roadmap for future collaborative studies of methane hydrates.

IV.2 WORKSHOP FORMAT

The two and a half day workshop included plenary lectures, panel discussions, small group break-out meetings, and a poster session. The final workshop program is provided in Appendix B of this report.

The workshop began with overview presentations on the research and development priorities and activities in Japan, Korea, and the United States. The speaker from Japan was Mr. Noboru Tezuka, Vice President of the Japan National Oil Corporation, the organization that administers Japan's national methane hydrates research program. The Honorable Dr. Shang-Hi Rhee, a member of the National Assembly and former Minister of Science provided insight into the methane hydrates R&D strategy in Korea. From the U.S., presenters included Ms. Rita Bajura, Director of the National Energy Technology Laboratory, who represented the U.S. Department of Energy, Dr. Bhakta Rath, Associate Director, NRL, U.S. Department of Defense, and Dr. Robert Heinemann, Chief Technology Officer of the Halliburton Company

The introductory talks were followed by technical lectures on seven subjects: (1) methane hydrate properties, with an emphasis on the influence of kinetic and thermodynamic parameters on formation and stability; (2) resource characterization and distribution; (3) analysis of the economic and environmental implications of resource development; (4) potential impact of methane hydrates on global climate; (5) Russian investigations; (6) benefits of international collaboration; and (7) the carbon dioxide sequestration field experiment as a template for international research collaboration.

On the second day, six concurrent breakout sessions were held to identify key challenges and to suggest means to address them through international collaboration. The breakout session topics were:

- Methane Hydrate Properties: The Influence of Kinetic and Thermodynamic Paramaters on Formation and Stability

- Methane Hydrate Resource Characterization and Distribution
- Environmental Concerns: Seabed Stability and Ecosystem Health
- Ocean Atmosphere Biosystems: Methane Impact on Global Climate Change
- Recovery and Sequestration of Hydrates on the Sea Floor
- World Energy Framework: Benefits of International Cooperation

The second day of the conference closed with presentations by the breakout session rapporteurs who reported their session's discussions and recommendations. The viewgraphs or slides employed by the rapporteurs for their presentations are included in Appendix C. Summaries of the rapporteurs's breakout session reports are provided in the following Section.

The workshop concluded on the third day with a panel discussion and an open forum to discuss next steps and to solicit recommendations from the participants. The workshop was adjourned around noon on 9 March 2001.

IV.3 BREAKOUT SESSIONS

Summaries of the six breakout session reports are provided below. Presentation materials can be found in Appendix C.

IV.3.1 Methane Hydrate Properties: The Influence of Kinetic and Thermodynamic Parameters on Formation and Stability

Three distinct "streams of interest" were identified by participants as comprising the framework for examining methane hydrate properties: field studies, laboratory studies, and hydrates for industrial applications.

Hydrate Field Studies

Two key research priorities are the observation and recovery of natural methane hydrate samples. The complexity of hydrates requires that researchers learn more about the mineralogy and morphology of hydrates, the effects of surface impurities, and the impact of chemotrophic microbial communities on hydrate formation and stability. Considerations include differentiating old hydrate samples from young ones; determining the variation in hydrate structure; assessing the effects of hydrate interaction with minerals; developing tools for *in situ* microscopic measurements; determining mass balances; and preserving natural hydrate/sediment composites for physical measurements.

Laboratory Studies

Researchers will need "pure" samples that can be prepared and analyzed under controlled conditions. Issues include identifying the phase boundaries and coexistence of hydrate phases; determining the rate of conversion of solid hydrate phases; obtaining accurate phase equilibrium data over an expanded range of pressures and temperatures, along with a determination of the phases; evaluating the variability of hydrate composition depending on growth conditions; assessing the effects of surface and colloid chemistry; identifying properties of hydrate films (agglomeration); and classifying hydrate morphologies. It is also essential: to develop the capability to link measurements of microscopic properties, such as structure and composition, with macroscopic behavior, such as decomposition; to measure time-dependent microscopic properties alongside macroscopic measurements; and to develop models for nucleation and kinetics.

Industrial Applications

Scale-up issues will be a primary focus of research on hydrate formation and stability directed toward industrial applications. Goals will include the development of processes to produce large quantities of hydrate by controlling kinetics and to form dense hydrates. Techniques also must be devised to preserve hydrates for several weeks for storage. Solving these challenges will require investigations to assess heat transport as a limitation to hydrate formation and to understand the complex effects of heat and mass transport.

Recommendations

The participants in this breakout session made two recommendations:

1. Establish an international database for scientific and technical information on hydrates; researchers and industrial stakeholders should share responsibility in the creation and management of this database.

2. Establish cross-disciplinary forums where empiricists, modelers, laboratory experimentalists, and others can interact.

IV.3.2 Methane Hydrate Resource Characterization and Distribution

Participants identified several R&D priorities for studies of the methane hydrate resource distribution and determining its characteristics: a systems model; scientific understanding; exploration methods; calibration and ground truth well control data; and type areas. It also was agreed that there is a basic need for reliable and accessible information sources and databases; and for scientific collaboration.

Systems Model

A hydrate systems model will be a key step in the development of the resource. This model would aid in determining the sources of the gas, its origin and age, the timing of its formation, and its biogenic or thermogenic characteristics, along with other formation characteristics. The model would be applied in determining migration of gas, including sedimentary controls, formation structure, and permeability. Another use of the model would be to simulate the "trap" where the hydrate is formed so as to address questions such as how a trap is formed, what mechanisms are involved in converting gas to gas hydrate, and where it is located. Finally, an accurate and robust model would enable researchers to assess gas loss from the system and other issues such as dynamic balance.

Scientific Understanding

While studies of gas hydrates have yielded significant data, greater understanding of the fundamental science behind gas hydrate formation, accumulation, and dissociation is necessary. Researchers must elucidate the scientific principles underlying hydrate formation and characterization; exploration methods; and the location and quantities of hydrates and their concentrations and spatial distributions.

Exploration Methods

Remote, geophysical, geochemical, and geological methods are currently available to explore the methane hydrate resource. Hydrate exploration will require ground truth. Viable methods will have to detect, map, and characterize the thickness, size, shape, composition and energy density of hydrates. Studies of the environments where hydrates form must be conducted. These investigations should examine geophysical characteristics, including seismic, electrical, and thermal, and seafloor expression and vents. Measurements can be calibrated using appropriate geochemical, biological, and physical parameter databases.

Calibration and ground truth well control data are available from the Ocean Drilling Program (ODP) wells in the Blake Ridge area, Cascadia in Canada and the United States, Mallik in Arctic Canada, and the Nankai Trough southwest of Japan. The ODP has yielded high-quality, down-hole, geophysical logs and core analyses for calibrations of the remote sensing measurements. Industry well data can be obtained and applied to develop, calibrate, and validate instruments and measurements. There is also a need for an *in situ* sampler, to overcome difficulties in collecting core samples from wells and transporting them to a laboratory for testing.

Type Areas

Geographical type areas must be identified as representative of hydrate environments. The most important type is a subduction zone with accretionary sedimentary prisms. These areas may contain the largest volumes of biogenic hydrates, but may not have the greatest concentrations; consequently, they may not be first targets for development. Two areas that have had drilling calibrations are Nankai and Cascadia, and a few others in Central and South America. Another area characterized by passive margin, non-hydrocarbon biogenic gas is the Blake Ridge, which has provided the most information to date. Off-shore hydrocarbon areas with thermogenic gas, or a mixture of thermogenic and biogenic gas, include the Gulf of Mexico, North Sea, various locations in Russia, the Caspian Sea, North Slope of Alaska, and a number of other locations.

Off-shore Arctic, permafrost and sub-permafrost areas include the Nomadic Arctic, Canada, Alaska, and Arctic Russia, where gas hydrate is commonly associated with accumulations of conventional hydrocarbons.

Collaboration

Participants agreed that there is a general need for shared information sources and databases on methane hydrates, as well as greater individual and organizational cooperation in this area.

IV.3.3 Environmental Concerns: Seabed Stability and Ecosystem Health

Environmental concerns involving methane hydrates will largely focus on the upper 200 meters of seafloor sediment, an area largely untouched by the oil industry, as well as the marine and global impacts associated with direct methane venting into the water column and potentially out into the atmosphere.

International Agreements

Promoting and establishing agreements with government and industry for geohazard information-sharing will be an important early step in assessing the environmental impact of hydrate development. Possible models include the Ocean Drilling Program and World Ocean Circulation Experiment. Both offer databases that are available to everyone; the data are evaluated and interpreted; and a central office coordinates data collection. Such a program would establish a mechanism for data-gathering and information sharing. Industry may also be willing to participate because many hydrate resource areas are not being actively explored for petroleum.

Characterizing Hydrates

Researchers will need to develop techniques reliably to characterize hydrates in the subsurface. There are no established techniques for examining the top 200 meters of sediment for hydrate formation and quantity. Since the condition of the sediment is relevant to the siting of oil platforms, seafloor stability issues should be of interest to oil companies.

Means are required to characterize hydrates with respect to the subsurface–particularly as relates to geochronology and undersea slides. Large slides on a slope can generate tsunamis, posing a potentially significant geohazard that is not well understood. It was noted in the discussions that falling sea levels can induce the slumping of sediments and impact hydrate stability. Researchers also need to determine the influence of gas on sediment geotechnical properties, particularly in the top 200 meters, because seeping gas and destabilizing hydrates can fluidize the seabed. Leakage of methane up to the seafloor by diffusion and advection, must be examined to measure its effects on the seafloor.

Impact of Production

Hydrate production will affect the seafloor. Researchers need to assess the impact of gas production from methane hydrates on seafloor stability and the potential loss of well control, including shallow flow.

Biogeochemical and Hydrate Interaction

Another research priority that was identified is studies of the interaction of local biogeochemical communities with gas seepage and hydrates.

Assessment Techniques

The group recommended the development of techniques to assess both localized and global effects of seepage and gas hydrates on ocean biogeochemistry.

Protocols

Geochemical, geophysical, and other protocols should be developed to detect and characterize hydrates in the subsurface, i.e., the upper 1,000 meters, as they may involve geohazards.

Department of Energy Website

Researchers recommended that the U.S. Department of Energy expand its Website to provide information on gas hydrates to an international audience.

IV.3.4 Ocean Atmosphere Biosystems: Methane Impact on Global Climate Change

The workshop participants focused on four areas related to research on the impact of methane sequestered in methane hydrates on global climate: research resources, research needs, approaches, and status.

Research Resources

In the United States, resources are or should be available in the near term to underwrite or sponsor studies on methane impact on global climate at the U.S. Department of Energy, National Science Foundation, National Aeronautics and Space Administration, Office of Naval Research, National Oceanic and Atmospheric Administration, and the U.S. Department of the Interior. Industry may be able to provide certain resources and funding, but its interest in this area and, therefore, its commitment, is uncertain.

Research Needs

Several research priorities were identified, including the development of *in situ* instrumentation for analyses of methane hydrates; development of a hydrate sampling system; establishment of standardized laboratory calibration; and securing of shared ocean-going vessel and submersible time for researchers.

Research Topics

There was consensus that the following research topics should be given priority:

- Comparing coastal zones to assess conversion versus stable margins for possible methane fluxes;
- Developing a predictive model of water column methane assimilation versus transport to the atmosphere;
- Improving the prediction of ocean thermohaline circulation;
- Developing an ocean carbon model to examine methane and evaluate $\Delta^{14}C$;
- Measuring the hydrate decomposition rate and stability;
- Studying bubble dissolution; and
- Developing an integrated model of the chemical, physical, and biological characteristics of sedimental methane hydrates.

International Collaboration

International research collaboration is essential. Significant benefits could be realized if partner organizations and institutions would cooperate to: study atmospheric $\Delta^{14}C$; select international sites for bubble studies; identify regions with shallow deposits and high hydrate loading; plan an interdisciplinary ice core and hydrate ocean circulation workshop; and share research facilities and laboratory and field resources and data.

IV.3.5 Recovery and Sequestration of Hydrates on the Seafloor

Several statements were offered as qualifiers for the future recovery of methane hydrates for energy and sequestration of carbon dioxide as hydrates: The field is in its infancy. The resource is considered to be vast, accessible, and of sufficient quality, but its economics are uncertain. Methane hydrates currently are perceived by industry more as a nuisance than a resource. Hydrate recovery has the potential to be commercially attractive, but the reality of near-term exploitation could resemble, say, a first-of-a-kind videocassette recorder that may cost $15,000, $1,500, or $150.

Summary of Research and Development

To date, the majority of research has been directed at resource characterization; much less effort has been expended to develop small-scale (low-energy) hydrate recovery and utilization concepts, such as for specialized defense applications. Methane hydrate recovery and CO_2 hydrate sequestration work, *per se*, is almost insignificant. Crude concepts for hydrate recovery have

been developed that could form the basis for determining which alternatives should be pursued. Some work is being done on methane hydrate transport systems for small-volume applications.

Research Needs

Industry has not aggressively pursued methane hydrate resource development because its economic benefits have not been demonstrated. Until a clear financial advantage emerges, the burden to support R&D will fall on government(s). The justification for this support will probably lie in energy security, price stability, environmental, and other public policy issues. Investments by government need to be made to ensure this resource can be tapped, say, 20 years from now. Participants recommended that an engineering systems analysis, budgeted at around $500,000, be conducted to assess alternative concepts for harvesting, trapping, refining, and transporting the hydrocarbons in seafloor methane hydrates. This systems analysis would identify the near- and mid-term feasibility of methane hydrates, as well as research and development needs. The relatively low cost of such a study suggests that it could be performed immediately.

Systems Analysis Structure

Several possible structures were proposed to undertake the systems analysis: (a) a national government(s)-funded program, with or without industry participation, or (b) a partnership of universities and national laboratories, possibly with private participation. Private companies could supply information and "reality checks." Intellectual property issues should not be an overriding concern in the early stages of the research.

The most likely research and development needs for scale-up of methane hydrate recovery will include securing accurate and extensive thermodynamic and kinetic data and transport properties. Various concepts to destabilize the hydrates *in situ* and extract the liberated methane or to mine and transport the solid hydrate need to be tested at the laboratory scale. Ultimately, a scale-up to a pilot-sized project will be necessary, at which time industry participation and intellectual property rights will become issues.

Alternatives

Should the proposed systems analysis structures prove unfeasible, then several alternatives can be considered: (a) piggy-backing on existing multi-national projects, such as the McKenzie Delta effort; (b) initiating a stand-alone multi-national project, such as the ongoing greenhouse gas ocean and geological sequestration projects; or (c) performing under a government-industry partnership, such as the U.S. Deep Oil Spill Project. Potential government funding sources include the U.S. Departments of Energy, Defense, and the Interior; International Energy Agency; or the New Energy and Industrial Technology Development Organization. A key question is whether the push to proceed will be driven from the top down or from the bottom-up, i.e., by the researchers or the funding agencies.

IV.3.6 World Energy Framework: Benefits of International Cooperation

Breakout session participants offered five primary recommendations to spur methane hydrate research and development. Adoption of the recommendations could lead to more effective research, particularly because hydrate data, at present, is scattered throughout the scientific literature, institute and company reports, and as unprocessed, uninterpreted information.

Increase Individual Cooperation

Increased scientist-to-scientist cooperation was proposed as a key to effective research. Such interaction could be facilitated through scientific meetings, bottom-up research, and "natural laboratories."

International Bodies

Interaction with international organizations should be encouraged. Such bodies include, among others, the Intergovernmental Oceanographic Commission of UNESCO, Ocean Drilling Program, International Geosphere-Biosphere Program, and European Union Sixth Framework Program.

Organizational Contacts

Contact should be encouraged between organizations and companies involved in the gas hydrates field, with special emphasis on the inclusion of small enterprises.

Database

As recommended by the other workshop groups, a database must be established for information-sharing. The database would include a website with information, links to national databases, and links to company databases.

Legal Issues

The final recommendation is that all agencies and organizations pursuing gas hydrates investigations and/or development review and consider well associated legal issues, such as existing and pending regulations and statutes, the Law of the Sea, International Seabed Association provisions, IPR, and royalties.

IV.4 PANEL DISCUSSION AND CLOSING SESSION

Professor E. Dendy Sloan, Jr. led the panel that included Ms. Edith Allison, U.S. Department of Energy, Dr. Georgy Cherkashov, Institute for Geology and Minerals Resources of the Ocean (Russia), Professor Chung Bo Kim, Inha University (Korea), Professor Bjørn Kvamme, University of Bergen (Norway), Dr. William Dillon, U.S. Geological Survey, Dr. Michael Max, Marine Desalination Systems, Dr. Peter Miles, Southampton Oceanography Centre (UK), Dr. Hitoshi Narita, U.S. Office of Naval Research-International Field Office, Tokyo, Dr. Lewis Norman, Halliburton Energy Services, Dr. John Ripmeester, NRC (Canada), and Dr. Amane Waseda, Japan Petroleum Exploration Co., Ltd. (Japan).

The following points were made by the panelists:

- The U.S. Department of Energy is supportive of multi-agency and international cooperative programs and will explore options via the U.S. Government interagency coordination group.

- The Department of Energy may be able to contribute significantly to the development of shared databases.

- The World Ocean government program in Russia which supports gas hydrate R&D encourages international cooperation.

- The Institute for Geology and Minerals Resources of the Ocean in St. Petersburg stands ready to share its data and technical resources and participate in appropriate joint projects; expeditions in the Norwegian Greenland Sea may be one option for expanded international collaboration and they are ready to make their research vessel available for such studies.

- Collaboration between groups and individuals with a range of expertise including geology, microbiology, oceanography, physical chemistry, and engineering is imperative to address the multi-dimensional subject of gas hydrates; successful cooperation must be implemented at the working level as individual researcher-to-researcher relationships.

- The value of additional planning workshops like the present one was called into question; it was suggested that scientific meetings where participants can focus on the science are of greater value; industry should be recruited to attend these meetings to be exposed to the scientific issues and engaged to cooperate at "the science level."

- In countries like Korea that may have a significant marine hydrate resource within its EEZ but does not have a coordinated national methane hydrates R&D program, international collaboration and networking is essential to lobby government support. Researchers in Korea are attempting to convince the government to invest in hydrates R&D; the cooperation of individuals and agencies from countries with established research programs will greatly enhance this effort.

- At present, Norway has no coordinated research program on gas hydrates, nor any program that could be adapted to this type of research. There does not appear to be any clear opportunities to secure funding through the European Commission fifth and sixth framework programs; however, it may be possible to obtain funding support in Norway for studies that focus on the environmental aspects of marine hydrates (e.g., hydrocarbon leakage from hydrate reservoirs), given the political interest in this area.

- In Norway and elsewhere, interest in methane hydrates is damped by the fact that conventional energy resources (e.g., natural gas) should meet projected demand for several generations. Hence, there is no immediate imperative to invest in developing methane hydrates as an energy resource. While government may be willing to fund R&D that will not yield a near-term return, the oil industry probably won't.

- While large oil companies and other major industrial entities may be hesitant to invest in what is perceived as a high risk initiative with limited or no return in the near time horizon, small, entrepreneurial companies are expected vigorously to pursue this opportunity; these companies are expected to do much of the early development.

- In the UK, there may be opportunities for research support under the Ocean Margins program (that examines development of the ocean margins, but requires 50% contribution from industry) and the new E-Science program. The E-Science program is interested in electronic information from the environment and may be a vehicle to initiate international collaboration on the development of shared databases.

- The U.S. Office of Naval Research-International Field Office has a policy to promote international R&D collaborations and views the topic of methane hydrates very favorably; like the Department of Energy, it will support multi-agency and international cooperative methane hydrates research programs.

- The oil and gas industry has an obligation to its shareholders to make money. Its charge is not to engage in elegant research programs or contribute to journals and science in general, but to make a profit. From this point of view, industry probably will not invest significantly in high risk research to develop a new energy source (i.e., methane gas from hydrates) whose production economics are very unclear, but may fund studies that support existing systems that produce natural gas. There continues to be interest by the oil and gas companies in areas relevant to ongoing exploration and recovery activities such as preventing or remediating hydrate blockage of subsea conduits in production areas, the collection and transport of stranded gas, seafloor stability, and certain environmental issues.

- There is no reality benchmark at this point in time for the commercial production of gas from hydrates. It was suggested, therefore, that a critical step in engaging industrial interest would be to provide proof of concept of a production system and to identify credible costs.

- The situation in Canada is similar to Norway, insofar as methane hydrates are not a priority since there are sufficient near term conventional energy resources. Researchers in Canada, however, have and will continue to cooperate and collaborate on international projects and welcome these opportunities.

- Japan has initiated the second phase of its national methane hydrate research program. The primary objective of Phase Two, which will run until 2005, is to develop a geological model and conduct gas production testing. As in the first phase, Phase Two will include a significant international component, including additional studies at the Mallik site. International participants in Phase Two will include researchers and agencies from the U.S., Canada, and Germany.

- It was observed that flow assurance issues (i.e., hydrate blockage of natural gas pipelines) will probably continue to be the primary interest of industry (and, therefore, the justification for funding) in methane hydrate studies for the foreseeable future.

- Two issues may provide the opportunity to convince industry to support studies that move the science "out of the pipeline." These issues are seafloor stability and the development of small gas fields where the cost of a pipeline or liquefaction facility cannot be justified. For these small fields, there may be sufficient interest in exploring hydrates as a medium to transport the gas.

- It was recommended that studies first be conducted at "sweet spots" that can offer the advantages of high concentrations of hydrates and free gas reservoirs. Production and transportation studies can be conducted under those favorable conditions to increase the probability of success; the results could then be transferred to lower concentration fields where conditions are more challenging.

During the open forum at the end of the workshop, conferees offered additional comments on research needs and cooperative research. The comments included:

- A number of conferees expressed concerns similar to those articulated by several of the panelists regarding the implications of the relative lack of interest in methane hydrates by the oil and gas industry. It was conceded that there would be limited interest in energy production from hydrates in countries that have ready and sufficient access to conventional oil and gas reserves; however, industry's immediate interest in flow assurance and seafloor stability should be leveraged fully to engage their support for hydrate R&D. The knowledge gained through studies directed at addressing these practical concerns (i.e., blockage and stability) should have significant general value.

- Successful demonstration of a (methane) production system would be essential to effect a change in industry's perception of methane hydrates as an energy resource. The idea of pursuing the first step in this direction at a "sweet spot" was again raised as well as the likelihood that small entrepreneurial companies would lead the charge.

- It also was suggested that the relevance of methane hydrates to topics other than energy supply be emphasized to engage the interest of other supporters. For example there is significant political and public interest in environmental issues such as global climate change and ocean development, both of which can be impacted by marine methane hydrates. From a military perspective, hydrates can result in bottom loss for low frequency sonar and affect navigation. Hydrates also could serve as an *in situ* (low) power source for specialized Navy surveillance and monitoring activities.

- Increasing public perception about methane hydrates, if done properly, could increase the amount of funds available for R&D. An outreach program should be considered.

- It was suggested that significant effort be made to initiate the process of putting in place international (government) commitments to pursue jointly funded studies. A critical step would be to select an appropriate site(s) for a field test.

- There are a number of developing countries that may have a need for the energy and a significant methane hydrate resource, but not the capital nor the technology to develop that resource. Cooperation with those countries could yield substantial benefits for all parties and should be seriously considered.

- It was proposed that future workshops have a greater technical focus and that researchers with a broad spectrum of interests and expertise be invited to present their work and discuss collaborations at the researcher-to-researcher level. Proposals could be developed at this workshop and representatives of potential funding agencies and industry would be invited to attend to critique and to consider these new initiatives.

V SUMMARY

An expert workshop on methane hydrates was held in Honolulu, Hawaii at the International Imin Conference Center of the East West Center on March 7-9, 2001. The workshop was organized by the Hawaii Natural Energy Institute of the University of Hawaii and the Environmental Quality Sciences Section of U.S. Naval Research Laboratory, in cooperation with the Hokkaido National Industrial Research Institute of Japan's Agency of Industrial Science and Technology, and Inha University of Korea. Grants of $10,000 each were awarded by the Office of Naval Research-International Field Office and the National Energy Technology Laboratory of U.S. Department of Energy to support the event. Additional funds were provided through the Hawaii Energy and Environmental Technologies (HEET) initiative sponsored by the U.S. Department of Defense through the efforts of U.S. Senator Daniel K. Inouye of Hawaii. The Department of Business, Economic Development and Tourism (DBEDT) of the State of Hawaii and the Pacific International Center for High Technology Research (PICHTR) also supported the workshop.

The workshop was the first in what is intended become a series of gatherings that will stimulate and support international cooperation in gas hydrate research and development. A second workshop is planned for the summer of 2002.

Fifty-eight participants from the United States, Japan, Korea, Canada, Norway, Russia, and the United Kingdom attended the workshop. Participation was by invitation only. Attendees included some of the world's leading researchers in methane hydrates, and representatives from government agencies and the private sector.

The principal workshop objectives were: (1) review past, ongoing, and planned methane hydrates R&D projects and programs; (2) share information on budgets and research resources and priorities in different countries; and (3) establish linkages for domestic and international partnering. The program of the 2-1/2 day workshop included plenary lectures, panel discussions, small group breakout meetings, and a poster session. It was conducted as a working event where all participants conferred to develop a roadmap for future collaborative studies of methane hydrates.

Specific research priorities were identified during the breakout sessions and are summarized in Sections IV.3.1 – IV.3.6 of this report. Highlights of those research needs generally fell in three categories–experiments; model development and analyses; and databases– and included:

Experiments

- observation, recovery, and analysis of natural hydrate samples;
- expand range of structural and thermochemical property data;
- establish standardized protocols and laboratory calibrations;
- development of tools for *in situ* microscopic measurements;
- development of field instruments to detect, characterize, and sample and transport hydrates;
- develop means to calibrate and validate detection and characterization instruments;

Modeling and Analysis

- development of a hydrates systems model;
- development of a predictive model of methane transport through the water column;
- conduct an engineering systems analysis for a methane gas production from hydrates;
- conduct an analysis of the environmental impacts of hydrate resource development;

Databases and Information Sharing

- perform a review and analysis of existing field data;
- establish a shared database;
- establish agreements for geohazard information sharing;

Other Issues

- perform a thorough review of relevant laws, statutes, and treaties

During the panel discussion and open forum on the final day of the workshop, there was a general consensus that, given the broad scope of the topic, international collaboration is essential to ensure that adequate R&D progress is made with the limited funds currently available. One obvious step in this direction would be expanded information sharing, possibly through the establishment of a comprehensive, accessible database. There was discussion about whether a top-down or bottom-up approach (i.e., collaboration driven by the funding agencies or by the efforts of researchers) would be more productive, with opinions expressed in support of both positions. Many participants articulated their concern over the relative lack of interest by the oil

and gas industry in methane hydrates as a future energy resource and conceded that industry participation would have to be engaged through their immediate interest in flow assurance, seafloor stability, and the development of small gas fields.

Comments and recommendations made during the panel discussion and the open forum included:

- The oil and gas industry has an obligation to its shareholders to make a profit. From this point of view, industry probably will not invest significantly in high risk research to develop a new energy source (i.e., methane gas from hydrates) whose production economics are very unclear. Industry may fund studies that support existing systems that produce natural gas. There is interest by the oil and gas companies in areas relevant to ongoing exploration and recovery activities such as preventing or remediating hydrate blockage of subsea conduits in production areas, the collection and transport of stranded gas, seafloor stability, and certain environmental issues.

- There is no reality benchmark at this point in time for the commercial production of gas from hydrates. Hence, a critical step in engaging industrial interest would be to provide proof of concept of a production system and to identify credible costs.

- While large oil companies and other major industrial entities may be hesitant to invest in what is perceived as a high risk initiative, small, entrepreneurial companies are expected to vigorously pursue this opportunity; these companies are likely to do much of the early development.

- It was recommended that studies first be conducted at "sweet spots" that can offer the advantages of high concentrations of hydrates and free gas reservoirs. Production and transportation studies conducted under such favorable conditions have an enhanced probability of success; the results could then be transferred to lower concentration fields where conditions are more challenging.

- It was suggested that the relevance of methane hydrates to topics other than energy supply be emphasized to engage funding support. For example, there is significant political and public interest in environmental issues such as global climate change and ocean development, both of which can be impacted by marine methane hydrates. From a military perspective, hydrates can result in bottom loss for low frequency sonar and affect navigation.

- Increasing public perception about methane hydrates, if done properly, could increase the amount of funds available for R&D. An outreach program should be considered.

- Significant efforts should be made to initiate the process of putting in place international (government) commitments to pursue jointly funded studies. A critical step would be to select appropriate sites for a field tests.

- There are a number of developing countries that may have a need for the energy and a viable methane hydrate resource, but not the capital nor the technology to develop that

resource. Cooperation with those countries could yield substantial benefits for all parties and should be seriously considered.

Appendix A: Registered Participants List

Fiery Ice from the Seas

The First Workshop of the International Committee on Methane Hydrates

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Appendix B:
Final Program of the First Workshop of the International Committee on Methane Hydrates

Fiery Ice from the Seas

The First Workshop of the International Committee on Methane Hydrates

PROGRAM

WEDNESDAY, MARCH 7

Registration and Continental Breakfast (Keoni Auditorium) **7:30 a.m.**

Opening Session and Welcome (Keoni Auditorium) **8:30 a.m.**

Stephen Masutani, Master of Ceremonies
Hawaii Natural Energy Institute

Michael Kitamura
Office of U.S. Senator Daniel Akaka

Richard Rocheleau, Director
Hawaii Natural Energy Institute

National Research and Development Overviews **9:00 a.m.**

Japan
Noboru Tezuka, Japan National Oil Corporation

Korea
Shang-Hi Rhee, National Assembly of the Republic of Korea

Halliburton Company
Robert Heinemann

Break (between presentations) **10:00 a.m.**

U.S. Department of Energy
Rita Bajura, National Energy Technology Laboratory

U.S. Department of Defense
Bhakta Rath, Naval Research Laboratory

Lunch (Wailana Room) **12:15 p.m.**

Technical Lectures (Keoni Auditorium) **1:00 p.m.**

Methane Hydrate Properties: The Influence of Kinetic and Thermodynamic Parameters on Formation and Stability
E. Dendy Sloan, Jr., Colorado School of Mines

Methane Hydrate Resources Characterization and Distribution
Joseph Gettrust, Naval Research Laboratory

Gas Hydrate: Resource or Hazard?
Roger Sassen, Texas A&M University

Break (between presentations) **2:30 p.m.**

Methane Hydrate and Potential Impact on Climate Change
Miriam Kastner, Scripps Institution of Oceanography

Natural Gas Hydrates: Russian Investigations
Georgy Cherkashov, Institute for Geology and Mineral Resources of the Ocean

World Energy Framework: Benefits of International Collaboration
Michael Max, Marine Desalination Systems

International CO_2 Field Experiment: A Template for Collaboration
Stephen Masutani, Hawaii Natural Energy Institute

Adjourn for the Day **5:00 p.m.**

Reception (Wailani Room) **5:30-7:00 p.m.**

THURSDAY, MARCH 8

Continental Breakfast (Keoni Auditorium) **7:30 a.m.**

Organizational Remarks (Keoni Auditorium) **8:30 a.m.**

Concurrent Breakout Sessions **8:45 a.m.**

(1) Methane Hydrate Properties: The Influence of Kinetic and Thermodynamic Parameters on Formation and Stability
(Keoni Auditorium)
Session Chair: Tsutomu Uchida; Rapporteur: John Ripmeester

(2) Methane Hydrate Resource Characterization and Distribution
(Pacific Room)
Session Chair: William Dillon; Rapporteur: Roy Hyndman

(3) Environmental Concerns: Seabed Stability and Ecosystem Health
(Kaniela Room)
Session Chair: Joseph Gettrust; Rapporteur:Charles Paull

(4) Ocean Atmosphere Biosystems: Methane Impact on Global Climate Change
(Kamehameha Room)
Session Chair: Miriam Kastner; Rapporteur: Richard Coffin

(5) Recovery and Sequestration of Hydrates on the Sea Floor
(Tagore Room)
Session Chair: Izuo Aya; Rapporteur: Craig Lewis

(6) World Energy Framework: Benefits of International Cooperation
(Keoni Auditorium)
Session Chair: Michael Max; Rapporteur: Lars Golmen

Lunch (Wailana Room) **12:00 p.m.**

Free Discussions and Rapporteur Report Preparation

Informal Poster Session (Keoni Auditorium)

Rapporteur Report Presentations (Keoni Auditorium) **2:00 p.m.**

Break **3:30 p.m.**

Adjourn for the Day 5:00 p.m.

Dinner Banquet (3660 on the Rise Restaurant) 5:30-7:30

FRIDAY, MARCH 9

Continental Breakfast (Keoni Auditorium) **7:30 a.m.**

Organizational Remarks (Keoni Auditorium) **8:30 a.m.**

Panel Discussion (Keoni Auditorium) **8:45 a.m.**

Closing Remarks **11:45 a.m.**

Adjourn **12:00 p.m.**

Appendix C: Break-out Session Summary Viewgraphs

Breakout Group 1

Properties: The influence of kinetic and thermodynamic parameters on formation and stability

Three streams: Hydrate field studies
Hydrate lab studies
Hydrates for industrial purposes

a) Hydrate field studies–observation and recovery of natural samples, *in-situ* production of hydrates, governed by complexity

Issues

Effect of: Complex mineralogy
Morphology
Surfaces
Impurities
Interaction with biological chemosynthetic communities

Nature of: Old vs. young samples
Cementing of minerals

Need for: Tools for *in-situ* microscopic measurements

Need to know: Mass balances
How to preserve hydrate/sediment composites for physical measurements

b) Laboratory hydrate studies–"pure" samples prepared and studied under controlled conditions

Issues

Need to know: Phase boundaries and coexistence of hydrate phases
Rate of interconversion of solid hydrate phases
Phase equilibrium data–higher P, lower T, with determination of phases
Variability of hydrate composition depending on growth conditions
Effect of surface and colloid chemistry
Properties of hydrate films (agglomeration)
How to classify hydrate morphologies

Need to: Link measurements of microscopic properties (structure, composition) to macroscopic behavior (decomposition)
Measure time-dependent microscopic properties alongside macroscopic measurements and modeling to develop models for nucleation and kinetics

Breakout Group 1 (continued)

c) Formation of hydrates for industrial purposes

Issues

Need to know how to: Scale-up from lab experiments
Make large quantities of hydrates by control of kinetics
Form dense hydrates
Preserve hydrate for several weeks

Need to know: heat transport as a limitation to hydrate formation
Effect of heat and mass transfer

RECOMMENDATIONS:

a) Establish an international database for scientific and technical information

b) Establish fora where empiricists, modelers, and lab. experimentalists can interact

Breakout Group 2

Methane Hydrate Resource Characterization and Distribution

A. Systems Model

B. Science Understanding

C. Exploration Methods

D. Calibration, Ground Truth
Well Control

E. Type Areas

F. Information Sources
databases

G. Scientist Collaboration
Organization collab.

A. Resource Model (economic) – where are the sweet spots

1. Source of gas – origin, age, timing, bio or thermogenic

2. Migration of gas – sedimentary controls, formation structure, permeability

3. "Trap" – accumulation of gas hydrate

4. Gas loss from system
   –dynamic balance?

B. Science Understanding

1. Geochemistry
   (Petroleum Systems)

2. Geology

   Structure

   Stratigraphy

   Etc.

C. Exploration Methods

How to detect, map, characterize thickness, size, shape, energy density

-geological environments

-geophysical – various seismic
electrical, thermal

-seafloor expression, vents, carbonate
geochemical, sampling

* -Technology Development

D. Calibration, Ground Truth
Well Control

1. ODP Blake Ridge area

2. ODP Cascadia, Canada/U.S.

3. Mallik, Arctic Canada

4. Nankai Trough, S.W. Japan

Other ODP
Industry well data

Need for *in situ* sampler–
pressure ODP, Germany, Japan

E. Some type areas; hydrate environments

-Subduction zone accretionary sedimentary prisms
(largest volume?), biogenic gas
Nankai, Cascadia

-Passive margins, non-hydrocarbon areas, biogenic gas
Blake Ridge

-Offshore – hydrocarbon areas thermogenic gas
Gulf of Mexico, North Sea
Russia, Caspian Sea, North Slope Alaska

-Onshore Arctic – permafrost - associated, hydrocarbon areas
Mallik Arctic Canada
Alaska, Arctic Russia

Breakout Group 3

Report of

Environmental Concerns-
Seabed Stability &
Ecosystem Health

Participants:

Charlie Paull
Joe Gettnust
Edith Allison
Jean Whelan
Michele Anderson
Lars Golmen
Bob LaBelle
Charles Helsley

Recommendations: International

1. Promote agreements (government & industry) to share information on geohazards (possible models: ODP, WOCE, etc.).

2. Develop techniques to characterize hydrates in subsurface, especially

   -geochronology with respect to slides (big slides cause tsunamis)

   -influence of gas on sediment geotechnical properties.

3. Impact of production on seafloor stability & potential loss of well control including shallow flow.

4. Interaction of local biogeochemical communities with gas seepage/hydrates (natural & anthropogenic).

5. Techniques to assess effects of seeps/gas hydrates on ocean biogeochemistry – global & local effects.

6. Develop protocols (geochemical, geophysical, etc.) to detect & characterize hydrates in subsurface from geohazard point of view (i.e., the upper 1,000 meters).

7. Recommend that DOE enhance website to make information on gas hydrate available internationally.

Breakout Group 4

Ocean Atmosphere Biosystems: Methane Impact

- Nina Rosenberg
- Patrick Takahashi
- Maurice Kaya
- Bill McCluskey
- Miriam Kastner
- Rick Coffin

i.e. U.S. Impression

Breakout Group 4 (continued)

Topics Addressed

- Resources
- Research Needs
- Approaches
- Status in Country

Breakout Group 4 (continued)

Resources

DOE
NSF
NASA
ONR
NOAA
Dept. Interior

?Private Industry

Research Needs

In situ instrumentation

Hydrate sample system

Laboratory calibration

Share vessel & sub time

Breakout Group 4 (continued)

Research Topics

I. Compare costal zones – conversion vs stable margins for possible methane fluxes

II. Water column methane assimilation vs transport to atmosphere – develop predictive model

III. Better prediction of ocean thermohaline circulation

IV. Ocean carbon model
   - put in methane
   - evaluate $\Delta^{14}C$

V. Decomposition Rate / Stability

VI. Bubble dissolution

VII. Integrate modeling for chemical physical, biological topic

International Collaboration

- Atmospheric $\Delta^{14}C$
- Select international sites for bubble studies
- ID regions in shallow systems with high hydrates loading for regions of concern
- Interdisciplinary ice core, hydrate ocean circulation workshop
- Share facilities

Recovery and Sequestration of Hydrates on the Sea Floor – Qualifiers

Qualifiers,…

- Small size of Group 5 is indicative of infancy (or futility) of recovery and sequestration of methane hydrates.

- Resource is considered to be vast, accessible, and of sufficient quality (?), but economics are uncertain.

- Perception: Methane hydrates are viewed more as a nuisance than a resource.

- Recovery has potential to be attractive but reality of near-term exploitation could resemble first-of-a-kind VCR that costs $15,000, $1,500, or $150.

Summary of Past, Ongoing, and Planned R&D Activities

- Majority of work has been directed at <u>resource characterization</u>; much less work is being aimed at small-scale (low-energy) recovery/utilization (e.g., defense) applications; almost insignificant work is being directed at recovery and sequestration *per se*.

- <u>State-of-R&D-Art</u>: Crude concepts for recovery have been developed; these would form basis for determining which alternatives should be pursued further.

- Some work is being targeted to methane hydrate transport systems (for "small volume" applications).

Breakout Group 5 (continued)

Identification of Research Needs

- Industry is sitting on sidelines because economics are not exciting. Burden thus falls on government(s) to take initial step (for energy security, price stability, and the long-haul) to support work needed to tap this resource 20 years from now.

- <u>Consensus</u>: First step should be Engineering Systems Analysis of alternative "concepts" (how to harvest/trap, where to refine, how to transport,...?) Systems Analysis (~$500K) will identify

    - Near- and mid-term feasibility (or suggest that Methane Hydrates I = Oil Shale II).

    - R&D needs.

- Is now the appropriate time to perform the Engineering Analysis? Small price tag suggests "yes!"

Identification of Research Needs (cont.)

- Possible Engineering Systems Analysis structure:
    - National government(s) fund Analysis (with or without industry support).
    - Universities and/or national labs (and private entities) perform Systems Analysis
    - Private companies provide information and reality check.
    - Intellectual property (IP) issues would/should not be overriding concern at this early stage.
- Likely R&D needs (for scale-up) will be:
    - Thermodynamic and kinetic data; transport properties (note, Group 1 will pay for this work, so Group 5 can concentrate on engineering).
    - Much of research can tap-off ongoing CO_2 hydrates work.
    - Ultimately, scale-up to pilot size is needed (IP becomes an issue)

Breakout Group 5 (continued)

Opportunities, Approaches, and Requirements for Collaboration

- Alternative means to perform Engineering Systems Analysis:
    - Piggy-back off existing multi-national projects (e.g., McKenzie, Japan/Norway,...).
    - Initiate stand-alone multi-national project.
    - Perform under government industry partnership (e.g., U.S. Deep Ocean Spill project.
- Potential funding sources (government):
    - DoE, DoD, DoI, NEDO, IEA,...
- Will motivation to proceed flow top-down or bottom-up?

Breakout Group 6

WORLD ENERGY FRAMEWORK: BENEFITS OF INTERNATIONAL COOPERATION

Chair: M. Max

Rapporteur: L. Golmen

Recommendations

1) Recommend increased scientist-to-scientist cooperation.
   - "Natural labs"
   - Scientific meetings
   - "Bottom-up" research

2) Encourage contacts with international bodies:
   - IOC
   - ODP
   - IGBP
   - EU 6th Framework Pr.
   - Others?

3) Encourage contacts between organizations & companies working on the GH issue.
   - Include small enterprises!

4) Recommend to establish a key DATABASE.
   - Web-site with some info
   - Links to national bases
   - Links to company bases

5) Recommend agencies involved in GH research to consider legal issues:
   - Current regulations
   - Law of the Sea?
   - International Seabed Association

- IPR
- Royalties